EXperts-Yachts
Normal & Coded Photogrammetic Targets
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***Mesures et calculs de stabilité - Jauge IRC***

J. SANS (07/01/2018)

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**https://www.uncl.com/2017/12/01/techniques-innovations/nouvel-ac-75-nz-jean/**

## Preamble

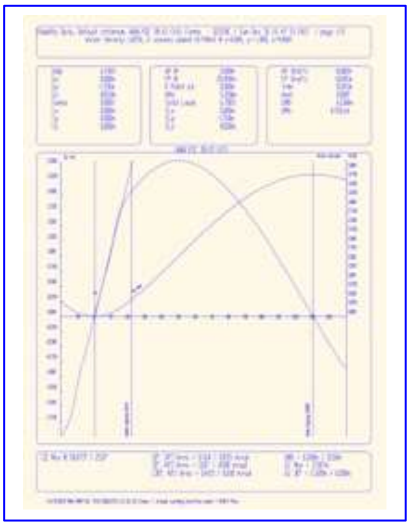
My previous paper of December 12,2017 was the translation of the video (synthesis image), of excellent quality from TEAM NZ, which presented the outlines of the new AC75.
The plans were deduced and dimensioned (this is the most important) from the images. The calculations were carried out using the very rare parameters known, namely an Archimedean displacement of about 7000 kg and an advertised speed of 22 knots on a single central foil and the rear foil.

This paper was only the technical summary of the reconstructed plans and calculations but also of my imagination.
Indeed, the transition from an Archimedean configuration to a Foiler configuration is not easy, especially for a 75' monohull. It's not enough to just take off, you have to evolve.
And if we refer to history, the first flights of the WRIGHT brothers really foreshadowed what an airplane would be like because they had also invented the technical means to control their aircraft, i. e., take off, turn, land.

For the AC75, the problem is the same: flying, OK it's pretty "easy", but starting a regatta, turning a buoy and race presents other difficulties.
If we add that to be successful, you will have to fly at a relatively constant altitude at all times, we understand that the difficulties are not minor.

## Some new hypotheses since my last paper

This AC75 thus evolves in two configurations, the first is Archimedean, the second is flight in support of lifting planes (Foiler).



First of all, the Archimedean configuration

I eliminate the "Dock Configuration", configuration where the boat is supported by tenders. In this configuration the boat is obviously Archimedean.

Then, before flying, it is necessary to get to the end of the runway and launch the aircraft to get out of the water, as the aircraft rolls on the runway and takes off. In both cases, this requires a target air speed (VR and then V2 for aircraft, depending on take-off weight and wing surface).

In this preparatory phase, the AC 75 should have good stability.

The study presented in the first paper assumed that the arms of the two central foils would be made of steel and that the foil part would be made of carbon composite.

Assumed weight estimates and stability calculations showed that the area under the stability curve needed to be increased. This meant that it was necessary to "lower the weight of the appendages" without having to install a bulb.

So I inverted the materials: the arms of the foils in carbon composite (monolithic) and foil in steel (a mass of 1750 kg), I imagined the rudder, to which is fixed the horizontal bearing plane, in steel. But the latter option may evolve.

This results in a maximum straightening moment of 17.2 T. m (Tons*meter) at 50° of heel (above curve).

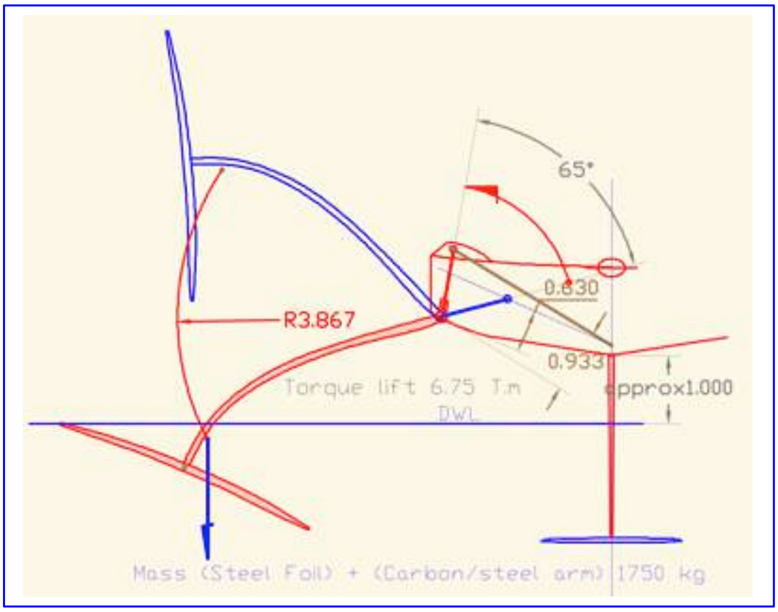
When the speed is reached, a "to nose-up" impulse must be given with the bearing plane of the rudder in order to increase the angle of incidence of the two lateral foils and "make the AC75 take off".

Quickly the ship will get out of the Archimedes regime. It then becomes necessary to control the AC75 in order to obtain a stable flight (constant height to water) regardless of the trajectory of the AC75. I will come back to the notion of theft in the next paragraph.

At this stage:

**Support on the two lateral foils + the rear lift plane**.

This will be the AC75 Regatta configuration.
Normally it should never return to the Archimedian configuration during the regatta.




Then comes the switch to "FOILER Optimal" configuration, i. e.:

- ✓ **Flying" on 1 single side foil + the AR lift plan**

This action requires technical means.
Indeed, it is necessary to lift the foil upwind, which requires energy. The mass of the foil and its arm and 1750 kg and its centre of gravity is 3.8 m away from its centre of rotation.

Some figures
Torque to lift the foil upwind: 17500 N * 3,867 m = 67670 m. N
Minimum lever arm during rotation to perform this operation: 0.630 m
Force required to be exerted on this lever arm: 67670 / 0.630 = 107400 N
Angle to browse: 65°
Operating time: 10 seconds
Angular speed: 0.113 rad/s
Power requirement: 7673 Watts (7.6 kW)

Each manoeuvre requires 7600 W * (10 sec) = 76000 Joules, or 76000 / 3600 = 21 Wh.

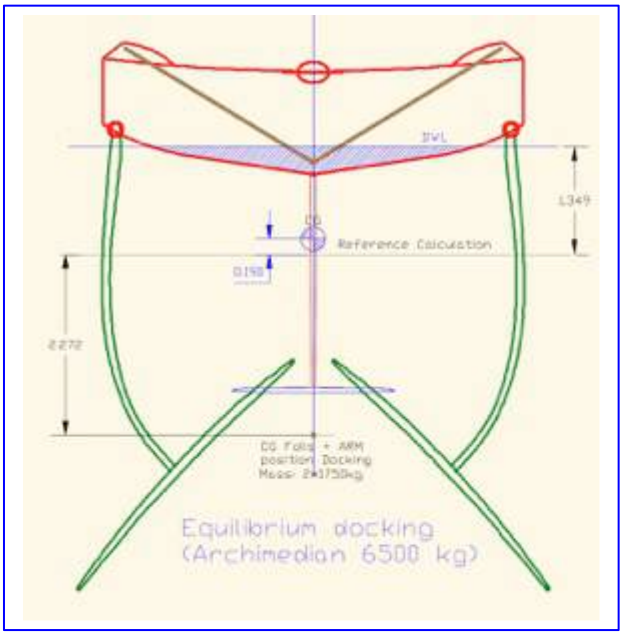
With each turn of tack in a regatta (2 manoeuvres of TB and BB foils), the consumption is therefore 42 Wh, i. e. with an electrical efficiency of 0.7:60 Wh.
That is almost 6.0 kWh for 100 transfers per day (2 regattas).
For information, currently it is necessary to count 85 kg of battery for 10 KWh (Lithium battery).
**Now let's look at the navigation of the AC75.**

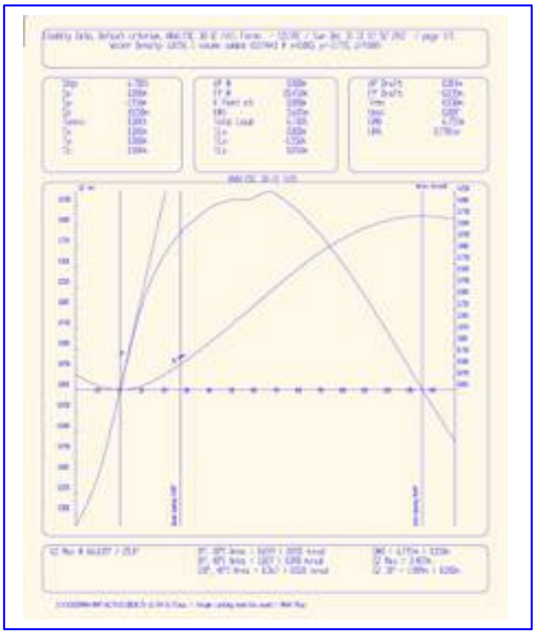
## Navigation

**This boat (which becomes an airplane) has 3 sailing configurations.**

***Configuration 1 (Archimedian mode)***

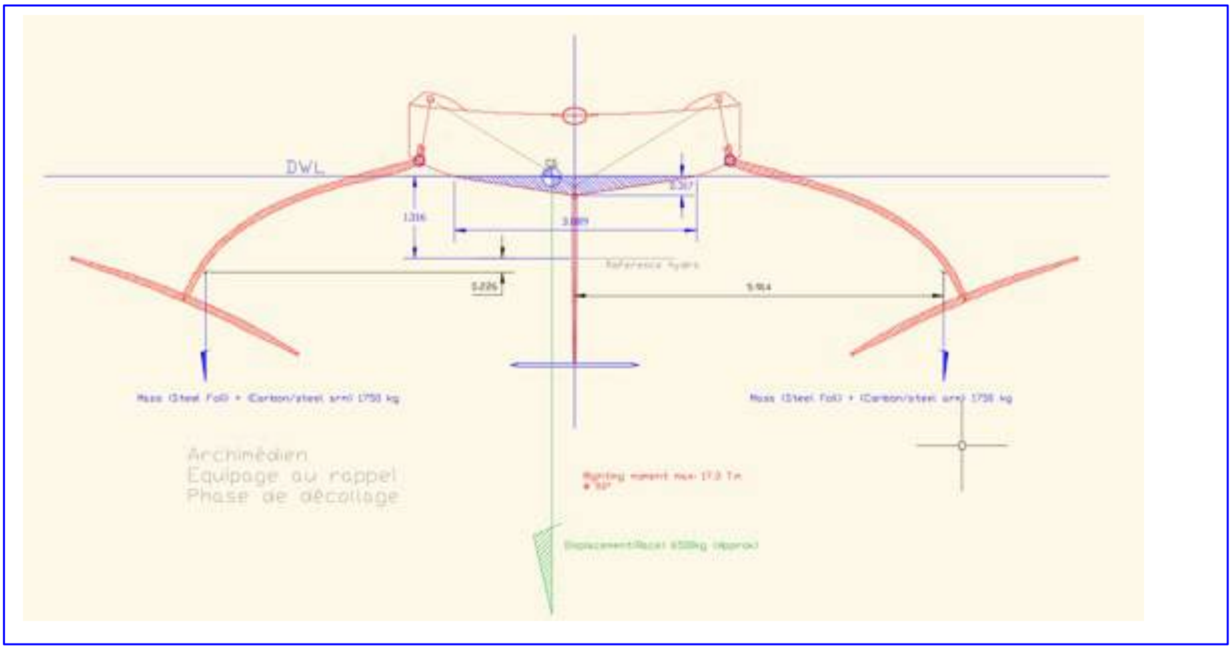
This is the time to leave the pontoon and join the regatta area. The foils are folded under the hull. One or two small boats tow the boat (tender).
Maximum stability.



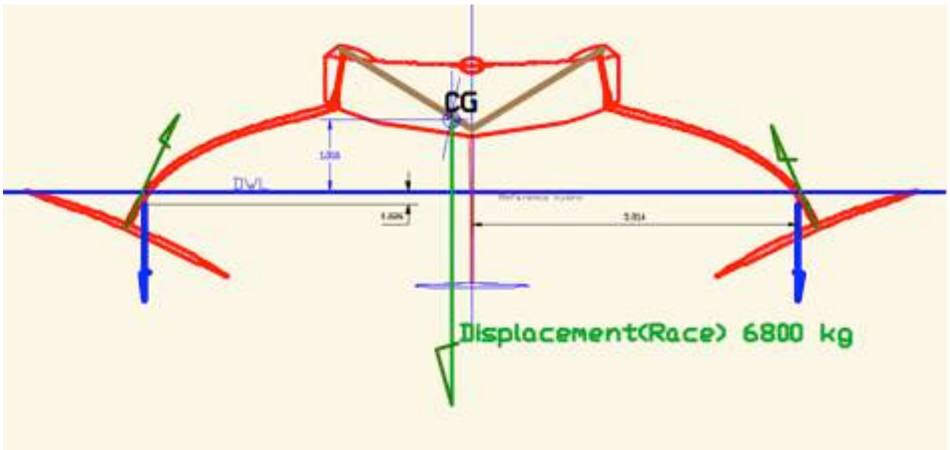
***Configuration 2 (Archimedian mode)***

The boat is still Archimedian, the foils are deployed to be in regatta configuration.



The crew is windward, which explains why the CG (Centre of Gravity is eccentric).
The boat is placed in a navigation position that produces the maximum speed (approximately 16 knots) in order to reach the flight area by relying on the 2 foils.

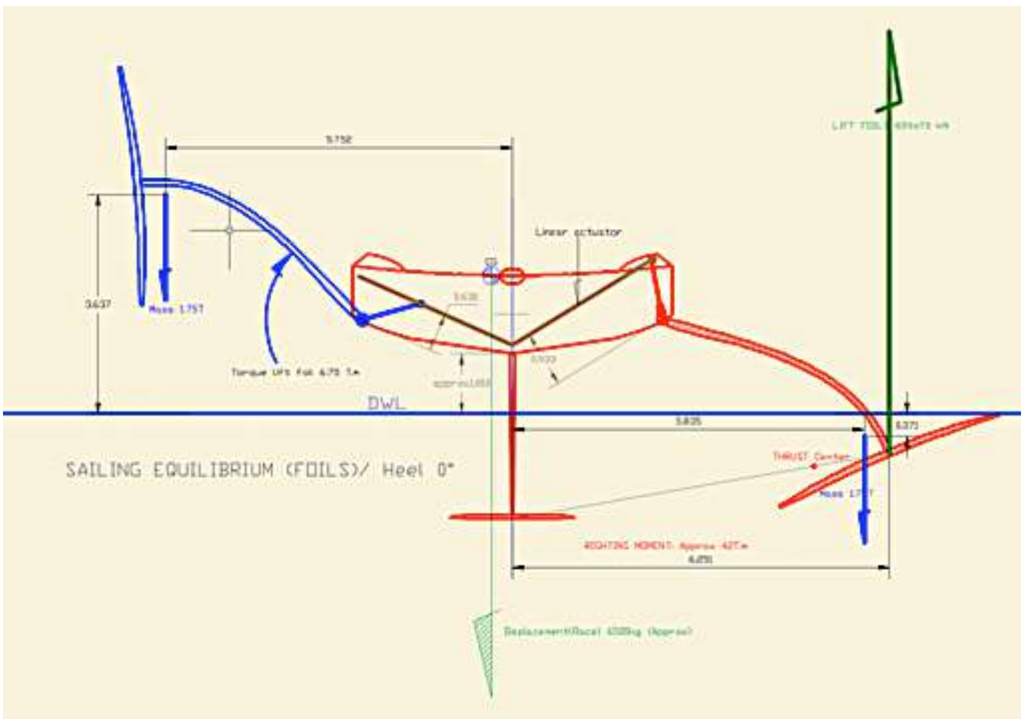
***Configuration 3 (switch from Archimedian mode to Foiler mode)***




In this configuration, weather conditions permitting, the boat then switches to Configuration 4 to sail on a single foil and the lift plane of the rudder.

***Configuration 4 (passage au mode Foiler « optimum »)***

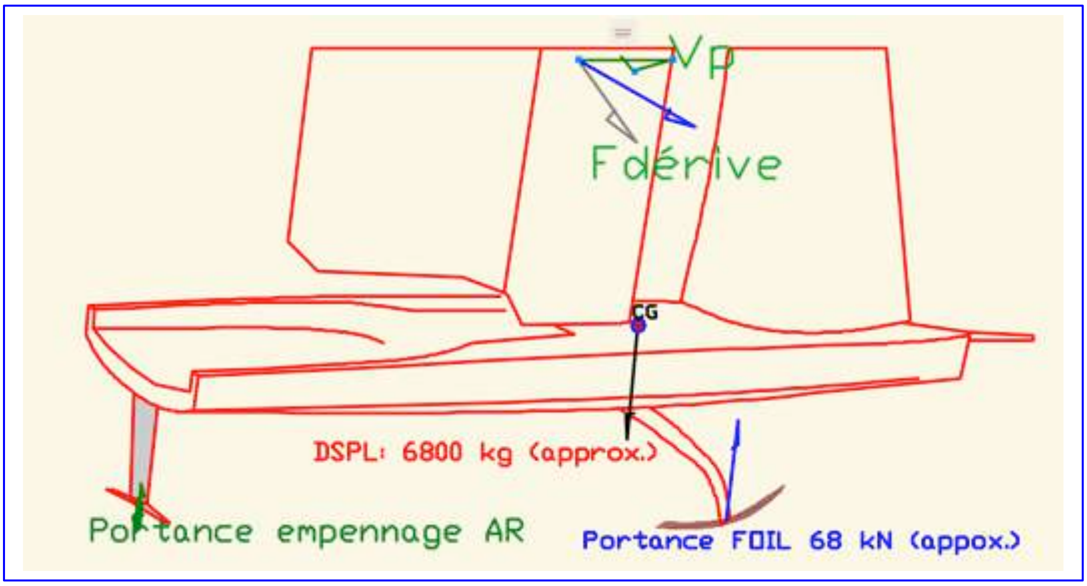
This will be the trickiest operation, as the AC75 will switch **from 3 points to 2 points**:
The two lateral foils produce the "LIFT" equivalent to the Displacement of about 7000kg, distributed over the 2 foils.
When switching to configuration 4, this "LIFT" of 70,000 N will have to be applied practically on a single side foil.
A "T" plan at the end of the rudder allows you to control the pitch and maintain the flight altitude, i. e. about 1 meter. It provides a lift of approximately 10-15%.




Contrary to what is said, the raised foil, which is windward, does not increase stability because there is one foil on each side (BB and TB). The resultant of the masses of these two foils is even downwind, because the lever arm of the active foil is more important than that of the raised arm!!

In fact, it is the crew that produces the (very weak) wind motion of the vessel's centre of gravity.

In 3D the following navigation configuration is obtained:

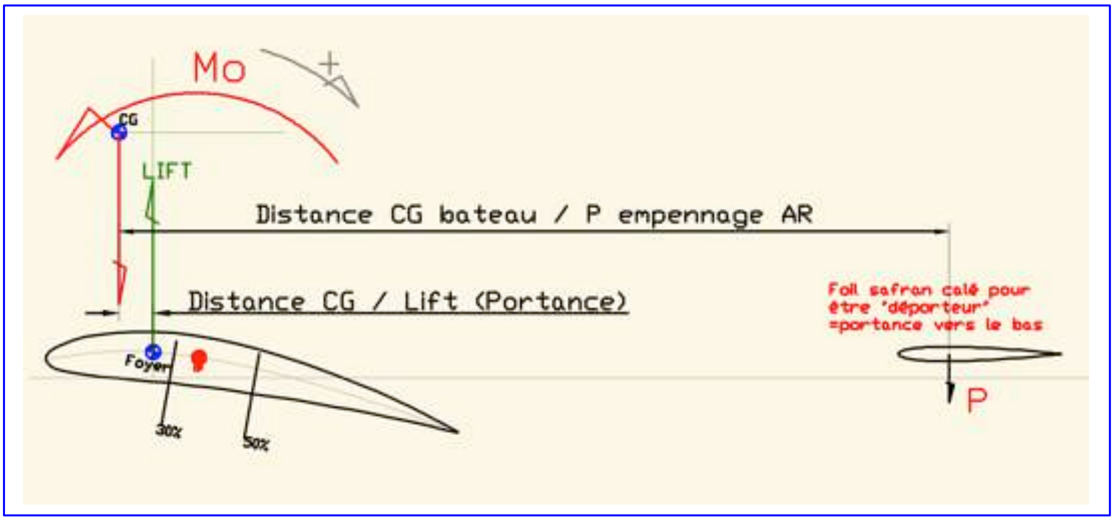



The 3D representation shows the total asymmetry of this configuration.
The support points (lift and control) are on a straight line, while on the AC45, they were in a triangle (two "T" s on the rudders and one foil in "L". leeward)
This configuration will complicate the piloting...

**<u>Theoretical longitudinal stability (airplane mode)</u>**

The AC75, as long as it flies on its two side foils while being controlled by the tail fin is fairly close to the configuration of an aircraft.
**Initially, propulsion will not be taken into account.**

The study focuses on the wings and rear empennage.




Both wings are fitted with a fixed angle of incidence relative to the aircraft body.
The grey horizontal line represents a parallel to the runway.

The CP Lift Centre (red point above) of a profile is the point of its cord around which the moment resulting from the aerodynamic forces applied to the profile is zero. Vertical Lift and Horizontal Drag apply at this point.

But in addition to the **lift and drag**, the effect of the asymmetric pressure distribution on the wing surface generates a moment of rotation around the lift center
This rotation moment will be noted Mo on the drawing.

The Centre of Lift (**CP**) evolves in longitudinal position according to the incidence of the profile.
It recedes when the angle of incidence increases.
The **CP** varies in position over a range of 30 to 50% of the profile rope.

In the end, a curved profile of a wing is almost always unstable in pitch due to the "**Mo**" moment.

**The horizontal empennage controls this pitch instability**.

The horizontal empennage is used to compensate for this tendency to "prick".
The vertical part of the empennage controls the trajectory.

The particularity of the horizontal empennage lies in its "down lift" setting. This means that it generates a downward lift.
The pilot will adjust the intensity of this lift to control the pitch.
In fact, we're actually making the rear empennage less efficient.

Because of its longitudinal mobility, the Centre of Lift (CP) cannot be taken as a reference for studying the longitudinal stability of an aircraft.

These calculations are performed using the Aerodynamic Center of the profile (also called "FOYER"), which is independent of the incidence angle. This "FOYER" is about 25% of the leading edge.

In order to keep a constant straight path, it is necessary that:

**The sum of the Force Moments around the CG (gravity centre) of the aircraft is zero**. (1)

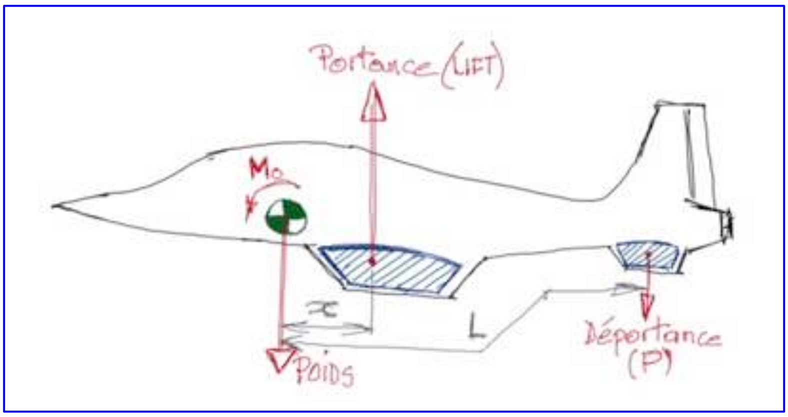
Let's have the next algebraic equality:

**P * (lifting lift arm) - Mo - (Lift arm Wing) * Lift wing= 0**

In the above configuration, the CG (aircraft) is ahead of the "FOYER", i. e. always ahead of the Lift Centre, regardless of its position in relation to the angle of incidence.

***Stable flight***

The GC is located in front of the "FOYER".
We're talking about "forward balance".
It is the "down lift" (P is directed downwards) of the empennage (symmetrical profile) that ensures the stability of the flight.
The pilot (autopilot?) will modulate the value of this lift (P) by slightly influencing the aerodynamic incidence of this rear plane.



The rule being when equation (1) above is true:

- P decreases, so the torque relative to CG decreases and the aircraft "nose down".
- P increases, torque increases, and the aircraft "nose up".

The lever arm being so large between the rear empennage and the CG, that the variations of incidence to generate on the rear empennage (thus of its lift) are very small. A fletner on the trailing edge ensures this function for minimum energy consumption.

However, this succession of "nose up or down" has to be managed in a balanced way so as not to generate uncontrollable longitudinal oscillations.

***Instable flight***

The CG plane's position is aft of the FOYER. We're talking about rear balance.

As the rear empennage is mounted with a spoiler (i. e. it is pushed downwards), control by the horizontal empennage becomes impossible.
The torques created around the CG by the lift and the rear empennage, are in the same direction.
The aircraft is not recoverable.

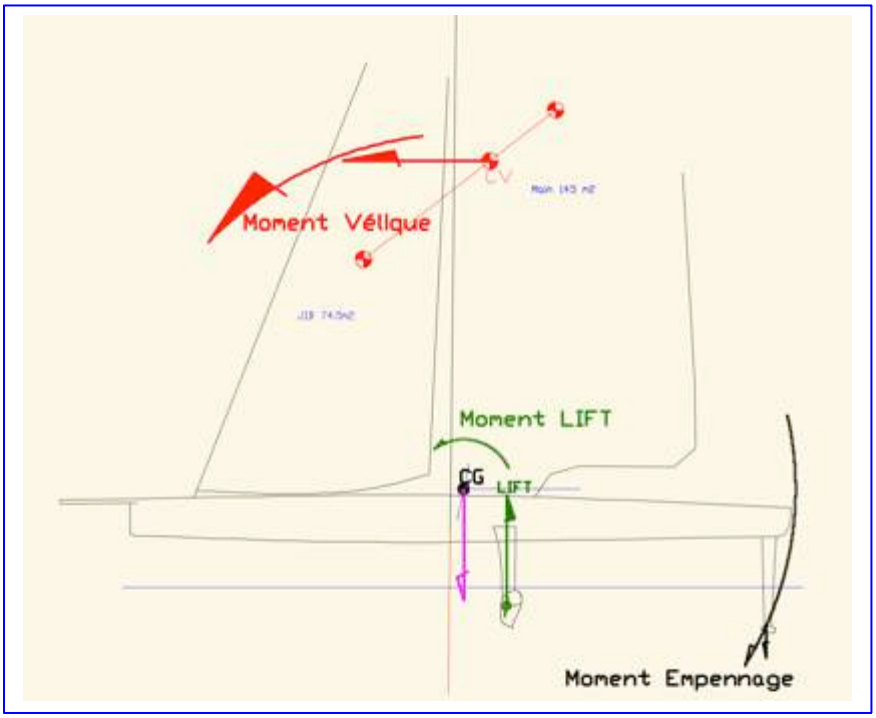
If the CG is slightly behind the "FOYER", then the situation is ambiguous, because the longitudinal position of the lift is changing, the CG may be forward (thus in a stable configuration), but the situation may deteriorate and it is then possible to find an unstable configuration.

Making sure that a CG is in front of the "focus" ensures that you always have a stable flight. But we must not exaggerate; because the more advanced the CG is, the greater the bearing capacity of the rear empennage must be. This requires flying with a high incidence of this horizontal empennage, therefore flying with drag.

**In the case of a FOILER, traction (the motor) complicates longitudinal balance.**

When you look at the 3D drawing at the top of page 5, there is the thrust of the sails that breaks down into Vp (forward force) and a lateral force that causes the boat to heel.

The VP force is located approximately 12 metres from the waterline in Archimedian navigation and slightly higher when the AC75 is on its foils.
Its effect creates a very important torque, which will tend to make the boat dive on the nose.




Opposite:
Forces and Moment present in the case of a forward balance, i. e. the CG of the vessel is ahead of the Foyer and therefore of the Centre de Lift.

We visualize very well that in this "forward centering" configuration, this velocity torque is in the same direction as that generated by the lift. The only antagonist torque is then provided by the rear empennage. This will force to steer strongly (incidence) this empennage thus generating a very important drag.

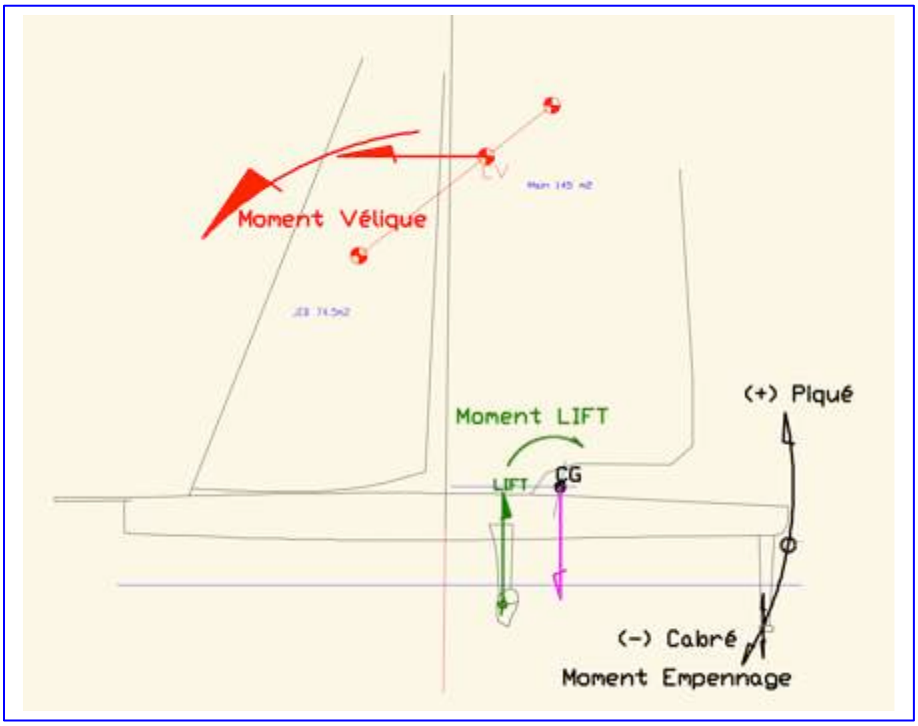
This is not the case for the longitudinal equilibrium of the aircraft, because the engine thrust or propeller traction is carried out practically in the horizontal plane of the Centre of Carriage or with a small lever arm (in the case of engines under the wings).

The position of the Velocity Center obligatorily requires a "rear balance".

The AC75, whether on its two side foils or on a single foil (lower wind) will be in balance around the CG (centre of gravity), or:

The centre of gravity (Longitudinal CG position) will find this position corresponding to the balance below.

It is clear that this position will be within a range. The rear tail that can generate lift up or down will ensure this balance.




**Mt vélique** = **Mt Lift** + **Mt Empennage**

In this case, the initial foil calibration is defined and fixed.

In case of unintentional rotation (up or down):

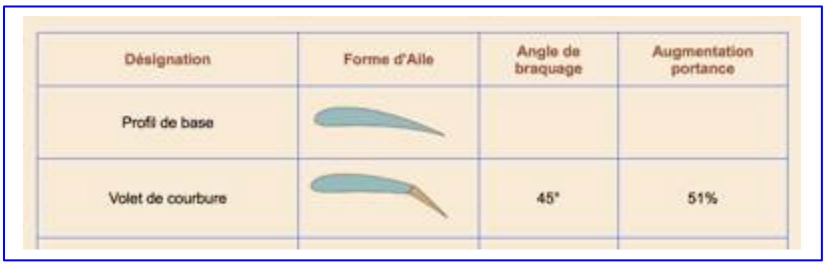
(a) The rear empennage is set in a "nose-down" position. This action causes a decrease in the angle of incidence and therefore the LIFT Moment.

b) Inversely, the aft "nose-up" rear empennage will cause an increase in the incidence angle and therefore an increase in the LIFT Moment.

The other solution is to set the forward and empennage foils with an incidence that produces lift (e. g. 80 /20%) and adjust the incidence of forward foils during navigation.

This method is viable on a small hydrofoil but practically impossible technically on an AC75 as it means that the two oscillating arms rotate around the horizontal axis perpendicular to the boat's axis.

However, this solution can be viable by modifying the curvature of the front foils with flaps on their trailing edges. The drag is probably higher than in the case of a variation in incidence, but mechanically this operation is relatively easy to implement.

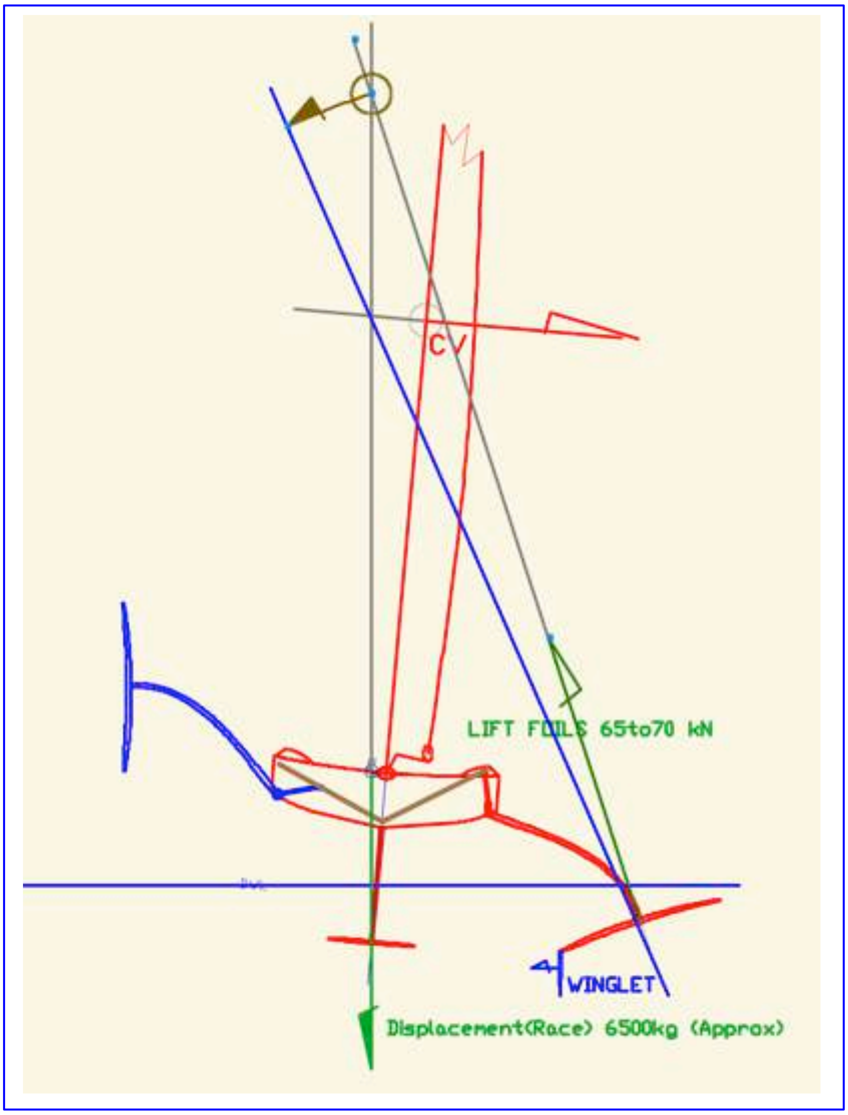


| Désignation | Forme d'Aile | Angle de braquage | Augmentation portance |
|---|---|---|---|
| Profil de base | | | |
| Volet de courbure | | 45° | 51% |

***But it is also necessary to take into account the transverse equilibrium produced by the sail.***

Assuming that the longitudinal equilibrium is under control, it must also be assumed that the velocity thrust produces a force perpendicular to the trajectory. This force can cause capsizing. It will produce heel and drift.

This force is about 5 to 6 times stronger than the propulsive force. Its point of application is in the Velic Centre, about 12 or 13 meters from the foils.




**Transverse equilibrium condition**:

The three forces:

Weight of the boat
Foil Pushing Thrust
Push produced by the sail.

Must be concurrent.

This relationship is very complex to obtain permanently because a parameter is totally independent of the pilot: the real wind speed.

Variations in the actual wind speed (and angle) of the actual wind affect the heel, and the speed of the Foiler, thus the thrust produced by the Foils.

Although it is possible to adapt the navigation to a drop in real wind speed by modifying the sail and the curvature of the foils, it is a complex operation that requires very short reaction times.

The situation is more complicated when the actual wind increases.
It is possible to adjust the sails by reducing its performance.
On the other hand, it will be impossible to lower the foil's performance downwind.
Modifying the TRIM of the Foiler by playing on the rear empennage will have very little influence on the angle of incidence (thus on the thrust produced) of the foil downwind.

The increase in thrust of the foil, will materialize by an increase in the depression on the extrados of the foil and lead to a phenomenon of ventilation and the abrupt stall of the foil.
The result will be a fall of the boat (he swings abruptly around the foil downwind).

On a small Foiler, like the MOTH for example, the pilot will permanently compensate these variations in wind and boat speed by playing on the transverse position of the centre of gravity [Boat + pilot]. The pilot will be in constant forward or rearward motion to maintain longitudinal and transverse balance to ensure transverse balance.

**This navigation mode is not possible on a 7000 kg Foiler.**

The solution will probably involve installing a Winglet at the end of the foil.
The load on the Winglet created by the Foiler's leeward skidding will tip the direction of the thrust generated by the foil (see above the arrow that shows the rotation of this direction).
In addition, the Winglet will generate, in fact, an anti-drift force that will be added to the anti-drift component produced by the foil.

It is also possible to change the angle of the dihedral of the foil, i. e. its "opening". The more the dihedral angle is "open", the closer the foil push is to the vertical and vice versa.
However, this operation is mechanically complex, because of the forces created by inserting the connecting arm and also because of the energy required to rotate the arm around its longitudinal axis.

***Fragile balance and flight stability***

It is therefore perceived that the development of the AC75, like its piloting, will be complicated. Moreover, unlike the record Foilers, whose range of use is very short, the AC75 will have to "FLIGHT" and especially "EVOLUATE in this configuration" during the whole regatta. A return to the Archimedian domain will surely be fatal.

***But before "FLIGHT" it is necessary to take off (Take Off)***

The AC75 has an advantage over other foilers in that it can choose its "take-off runway". This one will correspond to its best polar speed in the conditions of the moment.

It can thus benefit from a track long enough to take off gradually.

Indeed, the elevation to be achieved is low: about 1.3 meters. This condition requires you to leave the Archimedian mode with a very low slope if you don't want to burst the surface.

Based on the surface area of the identified foils on the video, the speed should be approximately 16 knots to fly on the two central foils.

The question is: Is it possible to reach a speed close enough to 16 knots, in order to gradually get out of the Archimedes mode?
The DLR is 21, which shows that we have a very light displacement. The ratio [Displacement/Sail area] is 0.78, which is favourable.
But there is the combined drag of the two [Arms + Foils], the rudder and the empennage.
This drag is more important than a conventional bulb keel.

Only a highly optimised VPP can tell whether with all these disruptive elements it is possible to reach a speed that allows the AC75 to be lifted gradually.

The method (if any)

a) In Archimedian mode, keep a horizontal attitude when playing on the rear empennage, i. e. with the initial incidence angle of the foils calibration (have as little drag as possible). The lift gradually lifts the boat.

b) As the speed increases, the pilot increases the lift on the forward Foils by changing the camber. It generates a couple who nose-up the Foiler.

b) With the horizontal empennage ("T"), it limits the rotation in order to obtain a "soft" transition from Archimedian mode to Foiler mode. But be careful not to "burst the surface". This moment of the piloting will be the most sensitive, because it will be necessary to round the trajectory in order to keep the foils in the water...

c) The AC75's lift planes evolve in water like those of an aeroplane in air, unlike the density of the two fluids.

e) If all goes well, the management to be followed will consist in managing the two balances (Longitudinal and Transversal).

***From the crew***

A crew of 10 is planned. This may be necessary.

We can imagine the following distribution:

- ✓ A helmsman who ensures the Foiler's trajectory.
- ✓ A Pilot who manages the flight in order to never return to Archimedes mode (take-off and then the stable flight).
- ✓ A Navigator who makes the water strategy.
- ✓ Several "Motorists" who take care of the Engine (setting the sails) to ensure a speed that allows you to fly permanently on two foils or one foil. The "Motorists" must be in permanent communication with the Pilot.
- ✓ Two "mechanics" who ensure the movement of the arms during manoeuvres (board turns, gybe)

***Mechanics for manoeuvring the central and rear Foils***

*Several mechanical solutions are possible; the same goes for energy sources.*

***Energy sources***

Two sources of energy will be used:

- ✓ Electricity stored in the form of batteries, probably lithium batteries.
- ✓ Hydraulics produced by a pump driven by an electric motor. I don't think we use a mechanical pump (coffee grinder), for reasons of speed of movement of the foils and especially of effort to produce to lift the foils (10 T).
- ✓ The hydraulic system requires 4 systems in series:

Battery + Electric motor + Hydraulic pump + hydraulic cylinder.

That is to say the product of 4 yields, which, even if they are each equal to 0.9, generates a final yield of 0.66.

It is also necessary to add the necessary oil reserve, because the oil warms up, which forces you to work with a large volume of oil in order to cool it down.

***Mechanical systems***

- ✓ Several systems are possible:
- ✓ Hydraulic cylinders
- ✓ Electrically driven ball screw jacks.
- ✓ Wheel and screw gear systems driven by an electric motor (with gearbox)

***Conclusion***

The history of Foilers propelled by sails, was more often written by engineers than by Naval Architects, who are naturally very attached to the Archimedian domain.

This is even more true, for monohull Foilers, since compliance with stability criteria limits architectural initiatives.

The idea of TEAM NZ is an interesting one, as it will make it possible to bring together competent multidisciplinary teams with financial resources.

It seems certain to me that after the next AC, we will have a vision of the Monohull Foilers with sails very different from what it is today.

Lorient le 7 Janvier 2017

Jean SANS